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Generation, Transmission and Wavelength Conversion of an 80 Gbit/s RZ-DBPSK-ASK Signal

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Abstract: An 80 Gbit/s RZ-DBPSK-ASK signal is generated using orthogonal phase and amplitude modulation. We demonstrate its transmission over an 80 km SMF+DCF fibre span, and wavelength conversion using FWM in a highly nonlinear PCF.

OCIS codes: 060.2330 Fiber optics communications, 060.5060 Phase modulation.

1. Introduction

Recently, multilevel modulation formats have been suggested for use in optical communication systems [1, 2]. Four-level phase modulation—differential quadrature phase shift keying (DQPSK)—has already been successfully used in a number of experiments, and transmission over transoceanic distances with very high spectral efficiency has been demonstrated [3]. Multilevel modulation can also be implemented by combining phase and amplitude modulation [2]. Generation of 40 Gbit/s signals using 10 Gbit/s equipment has been demonstrated by combining DQPSK and four-level amplitude shift keying (ASK) [4]. This opens up a new door for cost-effective generation of high-bit rate signals, as costly high-speed electronics are avoided. Another very attractive feature of multilevel modulation formats is that they allow for generation of signals with higher bit rates than state-of-the-art electronic and opto-electronic equipment. This has already been demonstrated for DQPSK, where signals with per-channel bit rates of 80 Gbit/s were generated using 40 Gbit/s equipment [5]. Thus, investigation of ultra-high bit rate systems is allowed without the complexity of optical time domain multiplexing (OTDM) techniques.

Wavelength conversion is expected to be an essential part of future all-optical networks. However, the most common wavelength conversion methods disregard the phase modulation, prohibiting conversion of phase modulated signals. This can be overcome by using four wave mixing (FWM), which offers phase-maintaining wavelength conversion, as demonstrated in [6] for low bit-rate differential phase shift keying (DBPSK) signals.

Here, we present generation of an 80 Gbit/s signal using a combination of DBPSK with ASK and return-to-zero (RZ) pulse carving at a symbol rate of 40 Gbuad. We prove the viability of such 80 Gbit/s RZ-DBSPK-ASK signals in optical communication networks by demonstrating both transmission over an 80 km fibre span and wavelength conversion using FWM in a highly nonlinear photonic crystal fibre (PCF).

2. Results and discussion

As shown in Fig. 1, light from a continuous wave (CW) laser was modulated using a Mach Zehnder (MZ) modulator driven with a 20 GHz clock signal having an amplitude equal to twice the modulator switching voltage

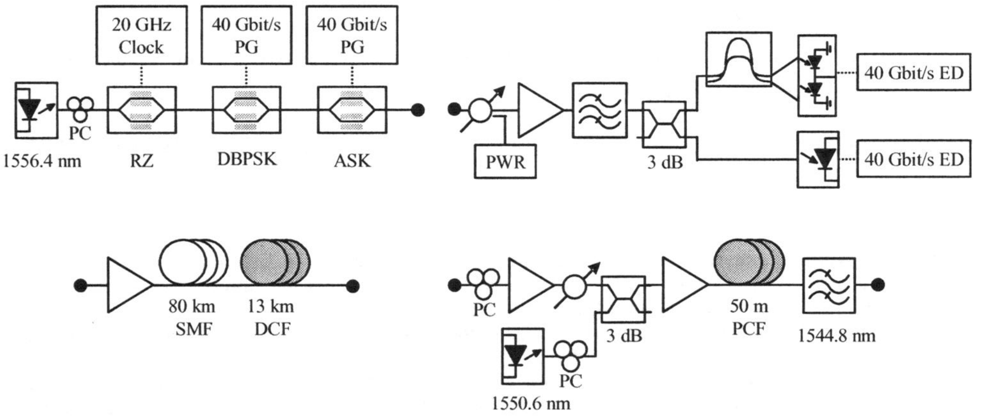

Fig. 1. Experimental setup showing the transmitter (upper right), the transmission span (lower left), the wavelength converter (lower right) and the receiver (upper right). PG: pattern generator, PWR: optical power meter, PC: polarisation controller, ED: error detector.

V_π. The MZ modulator was biased at a peak in the transfer function, resulting in a 40 GHz pulse train with full width at half maximum (FWHM) pulse width of 8.3 ps (33% of the symbol period). This pulse train was then phase modulated using a second MZ modulator biased at a null point and driven with a $2^{31}-1$ bit pseudo random bit sequence (PRBS) data signal having an amplitude equal to $2V_\pi$. Finally, the 40 Gbit/s RZ-DBPSK signal was amplitude modulated by a third MZ modulator driven with a $2^{23}-1$ bit PRBS data signal, where the MZ bias and drive signal amplitude were adjusted to obtain the desired extinction ratio on the ASK signal. The resulting signal was thus RZ-DBPSK-ASK with a bit rate of 80 Gbit/s.

The extinction ratio of the ASK signal was a trade-off between good eye opening for the ASK signal, and good eye opening of the DBPSK signal after demodulation. We found that an extinction ratio of 6 dB resulted in equal bit error rates (BERs) for both tributaries, and thus the lowest total BER. Therefore, an extinction ratio of 6 dB was used for all measurements.

At the input of the receiver, the signal was first amplified by an erbium doped fibre amplifier (EDFA) and filtered by an optical band-pass filter with a 3 dB bandwidth of 0.9 nm. Then, the signal was split into two branches, for the ASK and DBPSK tributaries, respectively. The DBPSK tributary was first demodulated using a 1 bit delay interferometer and then received using two 45 GHz photodiodes in a balanced configuration. The ASK tributary was directly received using a 50 GHz photodiode. Two 40 Gbit/s error detectors allowed for measurement of the BER of both tributaries simultaneously. The signal quality was quantified by the receiver sensitivity defined as the receiver input power resulting in a BER of 1.0×10^{-9}, when the BER was averaged over both tributaries. Eye diagrams of the generated signal and of the demodulated DBPSK tributary in the back-to-back configuration are shown in Fig. 2a and 2b, respectively. Six distinct traces are visible in the demodulated DBPSK tributary, due to differential demodulation of high-high, low-high, and low-low amplitude signals with either 0 or π relative phase shift.

A wavelength conversion experiment was setup up to demonstrate the possibility of wavelength conversion of such ultra-high speed phase and amplitude modulated signals. Wavelength conversion was realised using FWM in a 50 m PCF with a nonlinear coefficient γ=11.2 $W^{-1}km^{-1}$ [7]. The data signal at 1556.4 nm was combined with a CW pump at 1550.6 nm using a 3 dB coupler and amplified to 25 dBm (total power) and transmitted through the PCF. The spectrum of the signal at the output of the PCF is shown in Fig. 3, where generation of FWM products are clearly seen. At the fibre output, an optical band-pass filter with a 3 dB bandwidth of 0.91 nm was used to suppress all signals except the converted signal at 1544.8 nm. The PCF had a very low dispersion and dispersion slope, resulting in a walk-off between the signal and pump of less than 0.2 ps, thus allowing for very good phase matching. This is seen by the good conversion efficiency—defined as the ratio between the power of the converted signal and the power of the original signal at the PCF output—of –18.8 dB. The BER versus receiver input power measured

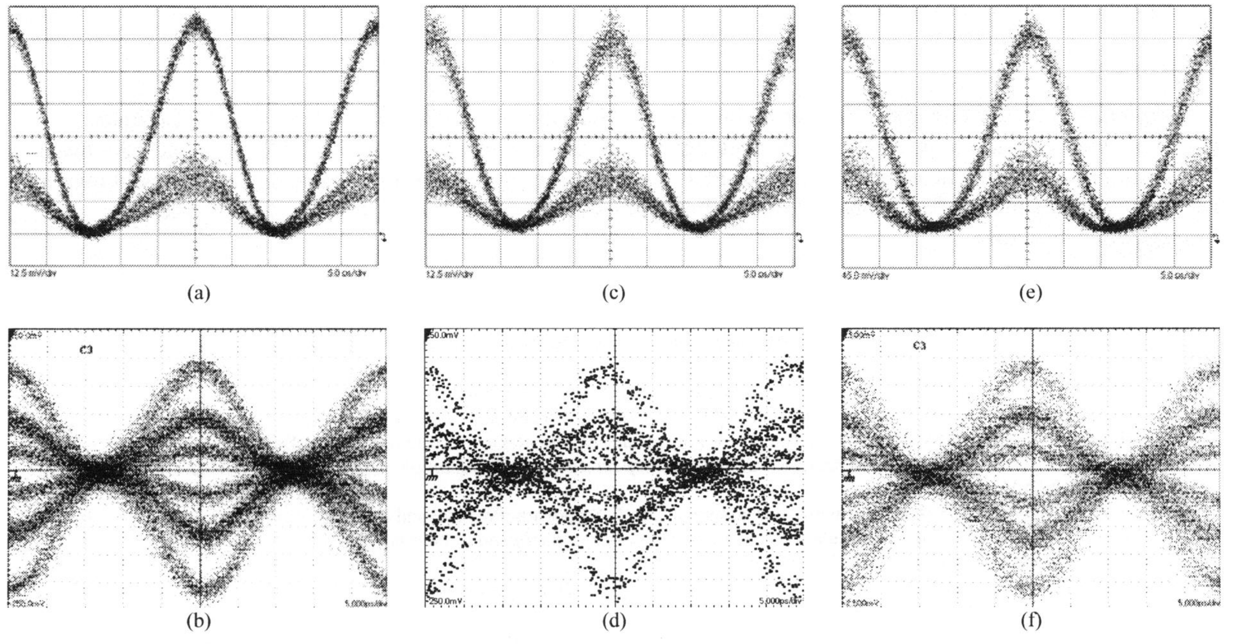

Fig. 2. Eye diagrams of the back-to-back signal (a)(b), after wavelength conversion (c)(d) and after transmission (e)(f), showing the ASK and DBPSK signal components, respectively.

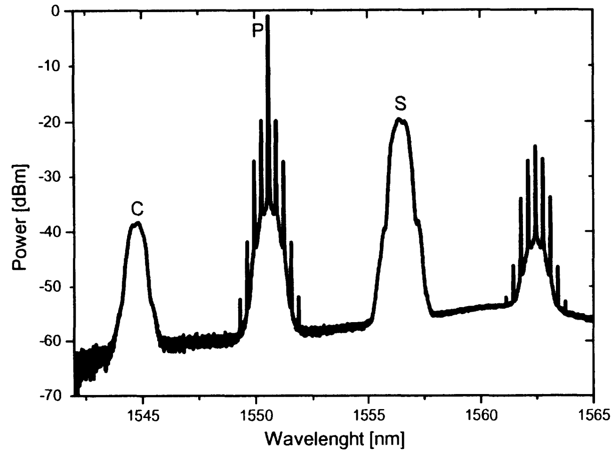

Fig. 3. Optical power spectrum of the signal at the output of the PCF, showing the signal (S), the pump (P) and the converted signal (C). Resolution bandwidth was 0.01 nm.

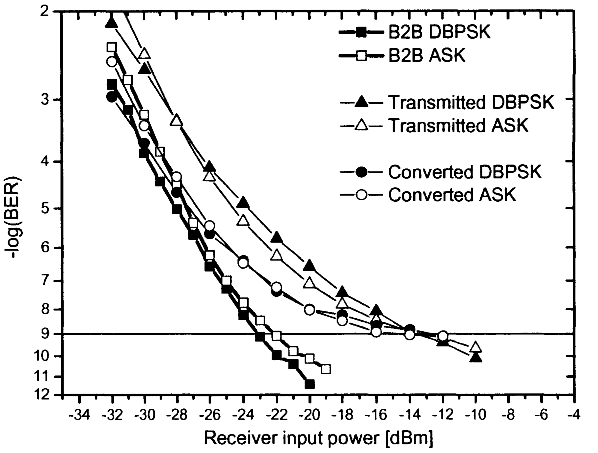

Fig. 4. BER versus receiver input power, showing the receiver sensitivity of both tributaries in the back-to-back configuration, after transmission and after wavelength conversion.

after wavelength conversion and for the back-to-back case are shown in Fig. 4. We find that the back-to-back receiver sensitivity is –22.5 dBm, whereas the sensitivity after conversion is –13.6 dBm. Noting that for low bit error rates, there is little or no penalty compared to the back-to-back case, we conclude that the primary degrading factor is reduced optical signal to noise ratio (OSNR) after the conversion stage. From the eye diagrams of the converted signal shown in Figs. 2c and 2d, it is clearly seen that the signal waveform is very well preserved after conversion.

Furthermore, the signal was transmitted through one 80 km fibre span to demonstrate the feasibility of such ultra-high bit rate signals in terrestrial communication systems. The fibre span consisted of 80 km of standard single mode fibre (SMF) followed by 13 km dispersion compensating fibre (DCF). The dispersion was 17 ps/nm/km for the SMF and –100 ps/nm/km for the DCF, such that the residual dispersion after the DCF was less than 5 ps/nm at the signal wavelength. Fig. 4 also shows the measured BER versus receiver input power for the transmitted signal, and we find that the receiver sensitivity of the signal after transmission is –13.2 dBm. From the eye diagrams of the signal after transmission, shown in Figs. 2e and 2f, we see that the waveform is well maintained. Some degradation is seen on the demodulated DBPSK signal due to cross talk from the ASK tributary to the DBPSK tributary by self phase modulation (SPM) in the fibre, as symbols with high amplitude result in a much higher phase change due to SPM than the low amplitude symbols.

3. Conclusion

We have demonstrated direct generation of an 80 Gbit/s signal using a combination of phase and amplitude modulation at a symbol rate of 40 Gbaud. Wavelength conversion of this 80 Gbit/s RZ-DBPSK-ASK signal was demonstrated using FWM in a highly nonlinear PCF. Furthermore, we successfully transmitted the signal over an 80 km SMF+DCF fibre span, demonstrating feasibility of using 80 Gbit/s RZ-DBPSK-ASK in optical communication systems.

4. References

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